

Formelsammlung I & D I

Diode

Diodegleichung

$$I_{AN} = I_S \left(e^{\frac{U_{AN}}{n \cdot k \cdot T}} - 1 \right) \\ = I_S \left(e^{\frac{U_{AN}}{U_T}} - 1 \right)$$

$$\text{mit } I_S = q \cdot A_D \left(\frac{D_p \cdot n_{p0}}{W_n - W_2} + \frac{D_n \cdot n_{p0}}{W_p - W_1} \right)$$

$$U_T = \frac{kT}{q} \quad n \dots \text{Idealfaktor}$$

Kleinsignalverhalten:

$$G_{diff} = \frac{dI_{AN}}{dU_{AN}} = \frac{I_S}{nU_T} e^{\frac{U_{AN}}{nU_T}} \approx \frac{I_{AN}}{nU_T}$$

Dynam. Verhalten:

Spezifische Kapazität: $C_j = C_{j0} \left[1 - \frac{U_{AN}}{\phi_i} \right]^{-M} \quad \frac{1}{3} \leq M \leq \frac{1}{2}$

$$\rightarrow Q_j = \int_0^{U_{AN}} C_j(U) dU$$

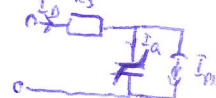
Diffusionskapazität:

$$Q_d = \tau_T I_S \left(e^{\frac{U_{AN}}{nU_T}} - 1 \right) = \tau_T \cdot I_{AN} \quad \tau_T \dots \text{Transitzeit}$$

$$\rightarrow C_d = \frac{dQ_d}{dU_{AN}} = \frac{\tau_T}{nU_T} I_S e^{\frac{U_{AN}}{nU_T}} \approx \frac{I_S}{nU_T} \cdot \tau_T$$

Dyn. Großsignal-ESB:

$$I_D \approx I_S \left(e^{\frac{U_{AN}}{nU_T}} - 1 \right) + (C_d + C_j) \frac{dU_{AN}}{dt}$$

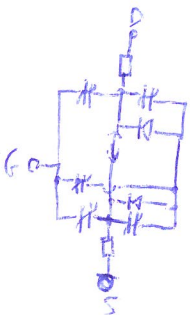


MOSFET

Stromgleichungen

$$\beta_{n/p} = \mu_{n/p} \cdot C_{ox} \cdot \frac{W}{L_{eff}}$$

(bei in Serie geschalteten: $L_{eff} = n \cdot L_{min}$)



↑

Großsignal-ESB

$$C_{Gi} = C_{ox} \cdot W \cdot L_{eff}$$

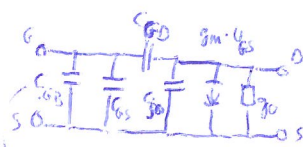
$$\text{mit } C_{ox} = \frac{\epsilon_0 \epsilon_{SiO_2}}{d_{ox}}$$

[bei Berücksichtigung d. Kanallängenmodulation:

$$I'_{Dn} = I_{Dn} (1 + \lambda_n)$$

$$I'_{Dp} = I_{Dp} (1 - \lambda_p)$$

	n-Kanal	p-Kanal
Sperrbereich	$U_{GSn} - U_{Tn} \leq 0$ $\rightarrow I_{Dn} = 0$	$U_{GSp} - U_{Tp} \geq 0$ $\rightarrow I_{Dp} = 0$
Widerstandsbereich (linearer Bereich)	$0 < U_{GSn} < U_{GSn} - U_{Tn}$ $\rightarrow I_{Dn} = \beta_n \left[(U_{GSn} - U_{Tn}) U_{DSn} - \frac{U_{DSn}^2}{2} \right]$	$U_{GSp} - U_{Tp} < U_{GSp} < 0$ $\rightarrow I_{Dp} = -\beta_p \left[(U_{GSp} - U_{Tp}) U_{DSp} - \frac{U_{DSp}^2}{2} \right]$
Sättigungsbereich	$0 < U_{GSn} - U_{Tn} \leq U_{DSn}$ $\rightarrow I_{Dn} = \frac{\beta_n}{2} (U_{GSn} - U_{Tn})^2$	$U_{GSp} \leq U_{GSp} - U_{Tp} < 0$ $\rightarrow I_{Dp} = -\frac{\beta_p}{2} (U_{GSp} - U_{Tp})^2$



entfällt falls nicht im Sperrbereich

Kleinsignal-ESB

Parameter: $g_m = \frac{\partial I_D}{\partial U_{GS}} \quad g_{mb} = \frac{\partial I_{OS}}{\partial U_{BS}} \quad g_0 = \frac{1}{r_0} = \frac{\partial I}{\partial U_{DS}}$

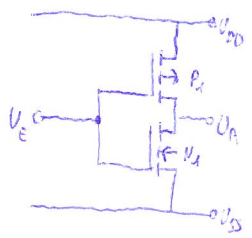
	C_{GB}	C_{GSi}	C_{GD}
Sperrbereich	C_{Gi}	0	0
Widerstandsbereich	0	$\frac{1}{2} C_{Gi}$	$\frac{1}{2} C_{Gi}$
Sättigungsbereich	0	$\frac{2}{3} C_{Gi}$	0

(falls Spektrum betrachtet:

$$C_{GSi} = C_{Gi} \\ C_{GD} = \frac{2}{3} C_{Gi} \\ C_{ji} = \frac{2}{3} C_{Gi}$$

CMOS-Grundsaltungen

Inverter



Dimensionierung

max. Störsicherheit $\rightarrow \beta_R = \frac{W_p}{W_n} = 2$

Verzögerungszeit

$$U_M = \frac{V_{DD} + \left[\frac{\beta_n}{\beta_p} U_{in} + V_{tp} \right]}{1 + \sqrt{\frac{\beta_n}{\beta_p}}}$$

für $U_{in} \approx 0,2 U_{DD}$ gilt: $t_{HL} \approx 4 \cdot \frac{C_L}{\beta_n \cdot V_{DD}}$

$$\left[t_{HL} |_{u_{in}=0,2 \cdot u_{DD}} = \frac{2 C_L}{\beta_n V_{DD}} \right]$$

$$t_{LH} \approx 4 \cdot \frac{C_L}{\beta_p V_{DD}}$$

$$t_p^* = \frac{1}{4} (t_{HL} + t_{LH}) \approx \frac{2 C_L}{\beta_n V_{DD}} \left[= \frac{2 C_L \cdot L^2}{C_g \cdot \mu_n \cdot V_{DD}} \right]$$

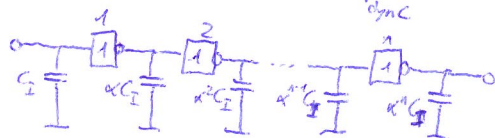
Lastkapazität

$$C_{L, int} = (2 C_{GD} + C_{jn}) (1 + \beta_R)$$

Verlustleistung

$$P_{avg} = \underbrace{f \cdot C_L \cdot U_{DD}^2}_{P_{dynC}} + \underbrace{2 f U_{DD} \left(\frac{1}{2} I_{DC} t_p \right)}_{P_{dynA}} \quad \text{mit } f = \text{Schaltfrequ.}$$

Treiberschaltung



[Aufgabe: Lastkapazität treiben]

$$\rightarrow n = \ln \frac{C_L}{C_I} \quad (\text{Inverter benötigt})$$

$$t_p = 2 \cdot \frac{C_I}{\beta_n V_{DD}}$$

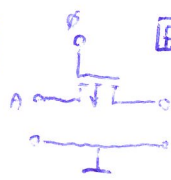
$$t_{pi} = \alpha \cdot t_p$$

$$\rightarrow t_{pn} = n \cdot \alpha \cdot t_p \quad \text{Verzögerungszeit d. Kette}$$

$$C_L = \alpha^n \cdot C_I$$

(minimal bei $\alpha = e$, in Praxis: $e < \alpha < 5$)

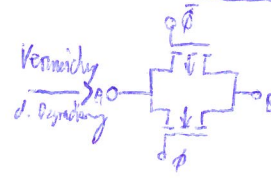
Transfertransistor



A	φ	B
1	1	2
1	0	1
0	1	2
0	0	$ V_{TP} $

A	φ	B
1	1	$U_{DD} - V_{TN} $
1	0	2
0	1	0
0	0	2

Transfer-Gatter

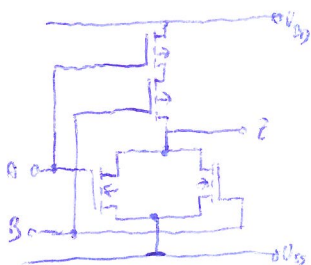


A	φ	B
1	1	1
1	0	2
0	1	0
0	0	2

— Degradierung d. Logikpegel

Logikschaltungen

NOR



Kompensation d. Stromtreibefähigkeit:

$$W_p = n \cdot \beta_R \cdot W_n$$

$$\rightarrow C_{GD} = n \cdot \beta_R \cdot C_{GDn}$$

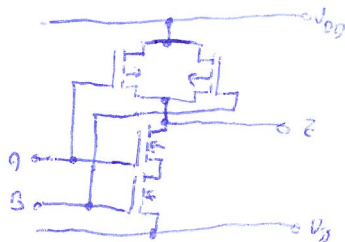
$$C_{jA} = \frac{1}{2} n \beta_R$$

$$C_{GDp} = \beta_R \cdot n \cdot C_{GDn}$$

$$C_{jBp} = n \cdot \beta_R \cdot C_{jBn}$$

$$C_{L, int} = 2n C_{GD} + n C_j + \beta_R n \left[\frac{1}{2} (n+1) C_j + 2n C_{GD} + 2(n-1) C_{GS} \right]$$

NAND



$$C_{L, int} = 2n^2 C_{GD} + 2(n-1) n C_{GS} + \frac{1}{2} (n+1) n C_j + 2n \beta_R C_{GD} + n \beta_R C_j$$

Kompensation d. Stromtr. $W_n = n \cdot W_{n0}$

Bestimmung d. Anstiegszeit

$$dV = C \cdot \frac{dU_C}{dt} \rightarrow \int$$

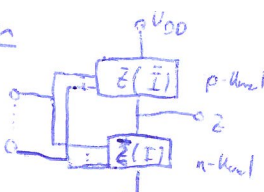
Ladung

$$Q = U \cdot C$$

Bel. Logikfunktionen

"•" = Parallel

"f" = Seriell



Bewertung von Kapazitäten

1) Nach Größe d. Kanals: $C_p = \beta_n \cdot C_n$

2) The Miller Effekt:

$$C_{inH} = 2 \cdot C$$

$$C_{inL} = C$$

$$C_{inH} = 0$$

Kippschaltungen

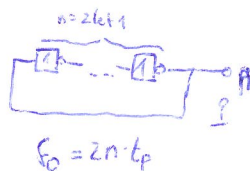


Kippschaltung	Repliziernetzwerk	
	Kv	Kr
Bistabil		
Monostabil		
Astabil		

$$T = R_T C_T \ln \frac{U_H}{U_L} \stackrel{U_H = \frac{U_D}{2}}{\approx} 0,69 R_T C_T$$

$$f_0 = \frac{1}{T_0} = \frac{1}{1,39 R_T C_T}$$

Ringoszillator:



Vgl. stat. CMOS ↔ Pseudo-NMOS

t_p	↓	↑ (da $C_{stat} > C_{Pn}$)
P	↓	↑ (Querströme)
A	↑	↓ (# Transistor)
Integrierbar	+	-
Logikpegel	H/L	L-Pegel degradiert (wenn beide Zweige leiten)

Sonstiges

Pseudo-NMOS:

$$I_{auf} = I_{Ent} \rightarrow I_p = I_n - I_p \rightarrow I_n = 2 I_p$$

$$\rightarrow \mu_n W_{eff} = 2 \mu_p W_p$$

$$\rightarrow W_p = \frac{1}{2} \frac{\mu_n}{\mu_p} W_{eff} = W_{n-eff}$$

Abfallzeit t_{HL} Q: $t_{HL} = \frac{\Delta Q}{I_{n,sat}} = \frac{C \cdot \Delta U}{I_{n,sat}}$

Inverter

$$\tau = - \frac{g_{m1} + g_{m2} - j\omega(C_{gp} + C_{Dn})}{g_{m1} + g_{m2} + j\omega(C_{in} + C_{iDp} + C_{gp} + C_{Dn} + C_L)}$$

$$\approx - \frac{g_{m1} + g_{m2} - j\omega(C_{gp} + C_{Dn})}{g_{m1} + g_{m2} + j\omega C_L}$$

$$\approx - \frac{g_{m1} + g_{m2}}{g_{m1} + g_{m2}}$$

Schaltsschleife:

$$U_H = \frac{U_{DD} + \sqrt{\frac{\beta_n}{\beta_p}} U_{TN} |U_{TP}|}{1 + \sqrt{\beta_n/\beta_p}}$$

$$\beta_n = \beta_p \quad U_{TN} = -U_{TP}$$

$$U_H = (U_E - U_{TN}) - \sqrt{(U_E - U_{TN})^2 - \frac{\beta_n}{\beta_p} U_{TN}^2}$$

Kennlinie: $\frac{\partial U_H}{\partial U_E} = V/U_{DD}$
→ Steigung in Sperrgebiet

$$V_{TH} = (R_W \cdot E_W) e^{-\frac{t_{tr}}{E_W}}$$

Addierer

$$C_{in1} = C_i + P_i C_i$$